SCIT: Ball Aerospace Team Study Activities

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Abstract: The Ball Aerospace team is working on its Study Phase contract activities for the Terrestrial Planet Finder (TPF) Structurally Connected Interferometer Structure Testbed (SCIT). We describe the main requirements for this TPF technology risk-reduction effort, our identification of primary challenges and issues, and some of the activities underway to meet those requirements and challenges and to resolve the issues.

TPF Structurally-Connected Interferometer (SCI) Concept

Science Goals - Minimum TPF Mission

1. Survey ≥30 stars for terrestrial planets
2. Measure planet orbits, masses, presence of biomarkers in the atmospheres (H_2O, O_3, CO_2, CH_4)
3. Observe astrophysical sources in MIR (7 – 17 μm) with ~ 50 mas resolution

Concept Description

1. Four 3.2-m aperture telescopes on 36-m linear truss (+ thermal shield, not shown)
2. Cryogenic Infrared Nulling Interferometer
   - To directly observe planets, star's light is canceled via destructive interference
   - Chopped Dual Bracewell architecture
3. Earth-Sun L2 Halo orbit for low disturbance environment, lifetime of 10 years

Key Enabling Technologies

1. Nulling Beam Combination
2. Large Deployable sunshade
3. Cryo Actuators
4. Precision Control & Stability (path lengths, angles, etc.)
5. Launch Packaging

Addressed by Structurally Connected Interferometer Structure Testbed (SCIT)

Structurally Connected Interferometer Structure Testbed (SCIT)

- SCIT contract objectives are to:
  - Retire highest level items on the list of issues, risks, concerns
  - Show capability of a structurally-connected interferometer structure to be part of an architecture to satisfy minimum TPF science requirements (search 30 stars for planets), not full TPF requirements (150 stars)
- To meet these requirements, the major challenges are to:
  - Design and build a sub-scale “deployed” structure supporting test masses representing SCI telescopes
    - Deployment features on the structure include hinges and latches
    - Structure stability traceable to TPF SCI flight-level performance needs
  - Gather accurate test data on the structure in a cryo environment
    - Employ disturbance sources to simulate TPF flight disturbances
  - Understand and characterize the performance of all critical structural elements, including after thermal cycling and observatory motions
  - Develop a reliable predictive and scalable model tied to test data
    - Model must be valid for cryo temperatures and zero-gravity

SCIT Teammates of Ball Aerospace

- U. of Colorado – Jason Hinkle and Lee Peterson have extensive experience in modeling and measuring high-stability behavior of aerospace cryogenic structures
- Princeton – Bob Vanderbei uses mathematics to find optimal structure configurations in terms of mass and stiffness ratios
- ATK-COI – designs, builds, measures, analyzes, and models high-stiffness, ultra-lightweight, cryo composite materials and structures
- Honeywell – designs, builds, measures, analyzes, and models vibration isolation and damping systems

Ball Aerospace personnel currently working on SCIT

- Bolinger, Laura -- Contracts
- Elias, Nick -- Science, Metrology
- Hardaway, Lisa – Technical Lead, Systems Engineering, Structures
- Kelsic, Beth -- Materials
- Kilston, Steve -- Manager, Science
- Lieber, Mike -- Modeling, Controls
- Linfield, Roger -- Science, Systems Engineering
- Lock, Jennifer -- Thermal
- Lund, Jack -- Subcontracts
- Noecker, Charley -- Science, Systems Engineering, Metrology
- Osterman, Dave – Integration & Test, Metrology
- Stephen, Michelle -- Metrology, Systems Engineering
- Ter-gabrielyan, Nick -- Metrology

SCIT in Context of TPF Program Life Cycle

Phase 1 -- **SCIT Activities** -- Phase 2

Study Phase Kick-Off – 9/16/03

Mid-Term Review – 11/11/03

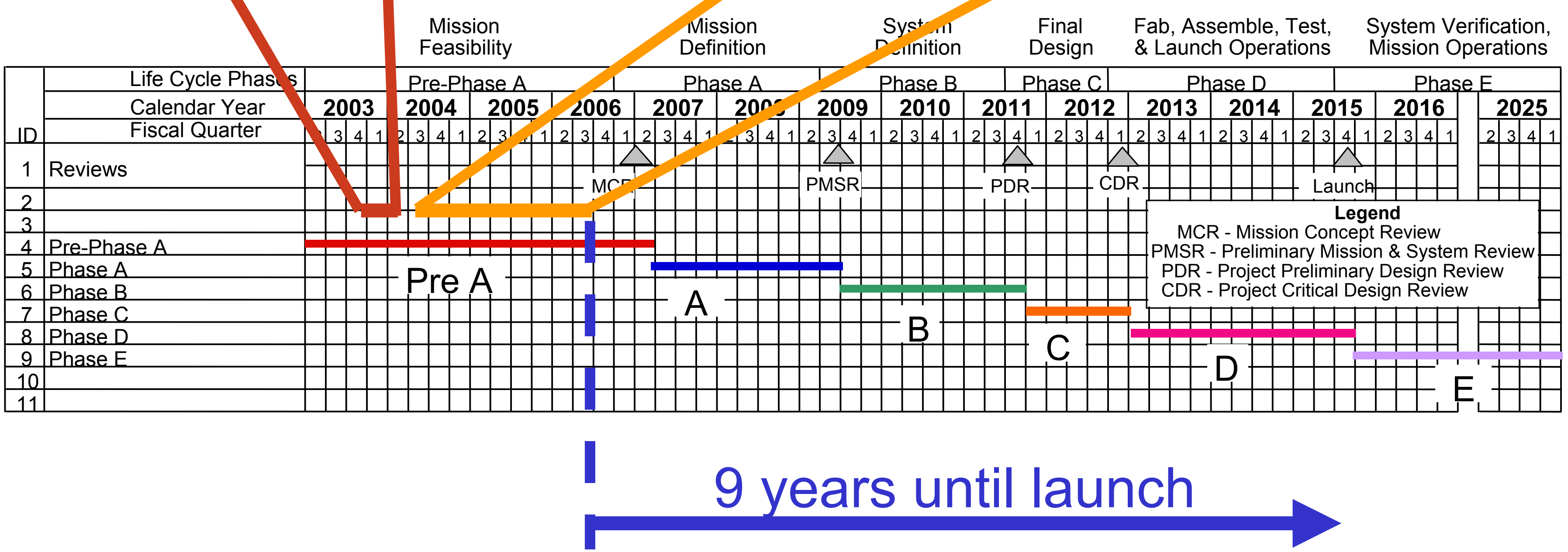
Prelim. Design Review -- 2/3/04

Final Report -- 2/16/04

Demonstration Phase Downselect – 4/19/04

Demonstration Phase Start – 5/15/04

Demo. Phase Finish – 6/30/06



Current SCIT Study Phase Activities

- Refine error budget: sub-allocate performance reqts. to structure elements
- Develop a preliminary SCIT design traceable to 0-g and cryo temperature
  - Details of test articles
  - Details of test facilities
  - Finite-element model (FEM) and integrated model
- Develop matrix of candidate structure and hinge/latch material properties.
- Perform trade studies on structure design, accounting for launch constraints
- Consider any new TPF issues, concerns, and risks, and potential responses
- Research and refine concepts for
  - gravity off-load and support system
  - methods for scaling to zero gravity
  - vibration isolation and damping systems
  - disturbance sources
  - position metrology
  - environmental monitoring sensors
  - sensors on the boom (accelerometers, vibrometers, thermometers)
- Begin modeling and scaling activities

Ball SCIT Functions

- Our testbed design is an all-inclusive SCIT facility
- Specific objectives include:
  1) Quieting the structural vibrations sufficiently for deep nulling
  2) Demonstrating measurement of structural distortions sufficient to control residual errors
     - Nanometer-level measurements at cryogenic temperatures to validate performance-prediction models for a 36-m flight TPF SCI
  3) Developing validated models of cryogenic structure performance
  4) Studying the long-term stability of the residual disturbances

Main SCIT Issues and Concerns

Challenges and Risks	SCIT Mitigation Feature
Sub-nanometer measurement	Modifying current techniques for cryo
Scaling measured behavior	Parameterization, dimensionless constants
Highly stable joints and latches	Subtracting known effects; testing of others
Vibration isolation & damping	Modifying current techniques for cryo
Adequate temperature regulation	Use of cryogenic chamber for testing

- Dominant disturbance for the TPF structure is most likely a reaction wheel assembly (RWA) rotating the instrument during observation
  - The RWA must turn the 36-m structure in a few hours, so it must be fairly large and heavy, with large disturbance torques and forces.
  - Vibrations must be attenuated for frequencies up to a few hundred Hz
- Stability requirements refer to 0.1 to 1 Hz variations in rms jitter
  - Steadying rms residual error in each control loop to these levels for 1 to 10 seconds requires sub-Å resolution of the residual disturbances

Final SCIT Study Phase Topics Emphasize Preparation for the Demonstration Phase

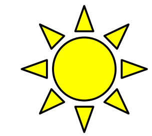
- Development Approach and Performance: Assessment & Discharge Plan
- Design Drawings
- Finite-Element Model (FEM) Description and Validation Plan
- Further Design and Modeling to Ensure Scalability
- Risk Areas and Mitigation Plan
- Cost and Schedule
- Assumptions Made
- Top Technical Concerns for SCIT and TPF SCI
- Enhancements Potentially Available
- Capabilities (Static and Dynamic Stability)
- Demonstration Phase Plan, including plans for collaboration with JPL
- Test and Metrology Design and Plan

Thanks !!

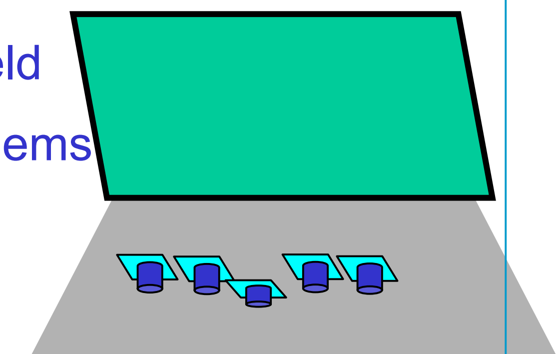
Extra Credit:
My Dark Idea

TPF Interferometer Field-of-Regard Problem – New Approach

- Problem – current field-of-regard radius limit 45 deg. from anti-sun
  - 30% of stars are out-of-bounds, so we need to look farther away
  - Rest of stars only viewable 6 months or much less every year

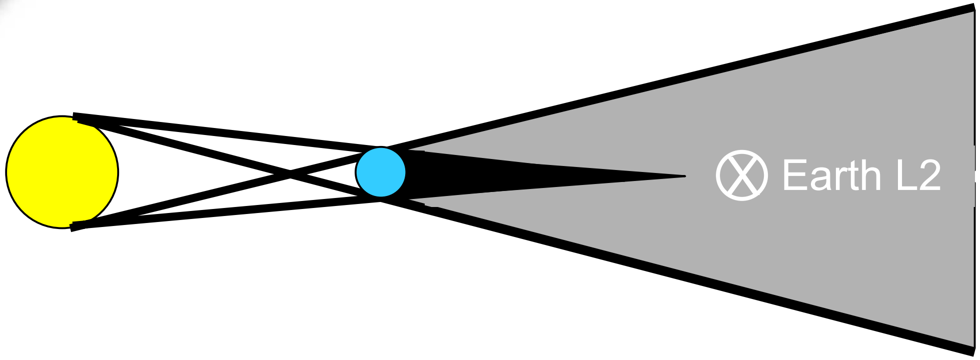


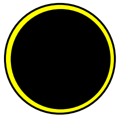
- One proposed solution is the “hen-and-chicks” scenario
  - Apertures point & move behind one large sunshield
  - Good for reducing both stray light & thermal problems
    - Could permit observations farther than 90 degrees from anti-sun
  - But:
    - Radiation pressure pushes on low-mass shield – it needs propulsion
    - Power for shielded spacecraft cannot be direct solar



- What we might like to find is a naturally shielded and fairly stable place in our solar system

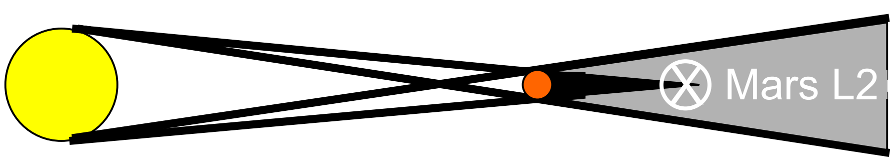
Umbras, Penumbras, and L-2 Points

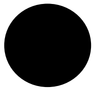




View of Sun from Earth L2

	Planet-Sun, AU	L2-Planet, AU	Sun Diam., °	Planet Diam., °
Earth	1.00	0.01004	0.528	0.486
Mars	1.52	0.00725	0.348	0.357





View of Sun from Mars L2

The Coldest, Darkest Stable Places in our Solar System

- Low mass-density planets have L2 points within “umbras”, natural “umbrellas” useful for space astronomy
  - Spacecraft temperature and stray light greatly reduced
  - Spacecraft power probably requires on-board nuclear source
- At Mars-Sun L2 point, about 1 million km past Mars,
  - S/C controlled within a 160-km diameter “cylinder” would stay inside 0.009 degree margin by which Mars subtense exceeds Sun subtense
  - Mars’ eccentric orbit slightly complicates orbit control operations
- For a TPF/Darwin interferometer at Mars L2
  - Nuclear power provides long-life orbit & formation control via electric propulsion
  - Communications with Earth via a Mars-orbiting laser-link spacecraft
  - Local zodi lower than for a 1-AU solar orbit
  - Getting there should be possible because of reduced launch mass:
    - Apertures smaller (stars closer), sunshields absent, passive cryo
    - These factors might also enable closer, man-made “hen and chicks”

Thanks Again !!!